(12) UK Patent Application (19) GB (11) 2 277 803 (13) A

(43) Date of A Publication 09.11.1994

(21) Application No 9309221.1

(22) Date of Filing 05.05.1993

(71) Applicant(s)
Jerry Geoffrey Assenheim
28 Athenaeum Road, Whetstone, LONDON, N20 9AE, United Kingdom

(72) Inventor(s)
Jerry Geoffrey Assenheim

(74) Agent and/or Address for Service
Jerry Geoffrey Assenheim
28 Athenaeum Road, Whetstone, LONDON, N20 9AE, United Kingdom

(51) INT CL^5
G01N 22/04

(52) UK CL (Edition M)
G1N NCCR N19B2A

(56) Documents Cited
GB 2271637 A GB 2260408 A GB 2202947 A
EP 0292571 A

(58) Field of Search
UK CL (Edition M) G1N NCCR
INT CL^5 G01N
ONLINE DATABASES: WPI

(54) Microwave moisture determination

(57) A moisture measuring system uses the technique of measuring both parameters of the complex dielectric constant of the material containing water to correct for the density of this material.

The electromagnetic field of a microwave resonator is allowed to link with the moist sample and the changes in Q factor and resonant frequency of the resonator are determined.

The change in frequency is measured by a technique comparing the phase of the voltage in the resonator with the phase of a voltage due to the delay in a coaxial cable. Two microwave diodes D1, D2 rectify the difference between these two voltages to produce an output which is a linear function of the small frequency change.

A simple analogue circuit is proposed to use the two parameters obtained to obtain a reading of moisture which is independent of density of the material.

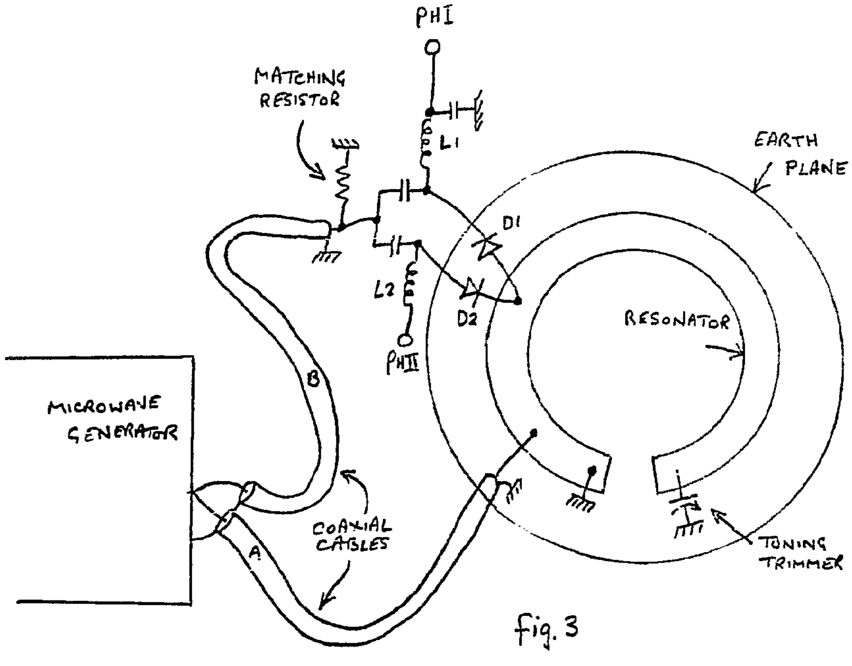

fig. 3

CONNECTIONS TO RESONATOR

GB 2 277 803 A

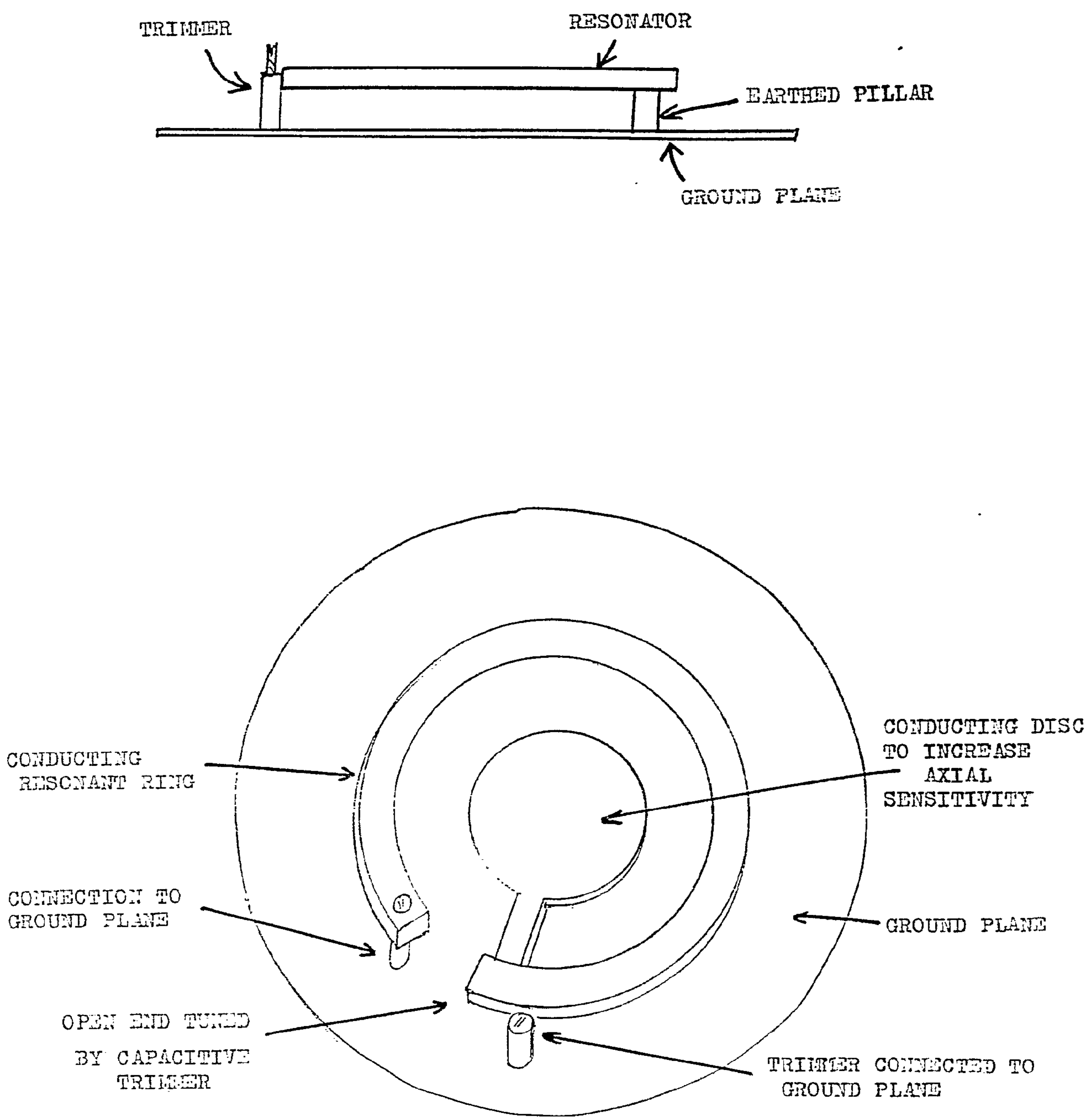
TRIMMER
RESONATOR
EARTHED PILLAR
GROUND PLANE
CONDUCTING RESONANT RING
CONDUCTING DISC TO INCREASE AXIAL SENSITIVITY
CONNECTION TO GROUND PLANE
GROUND PLANE
OPEN END TUNED BY CAPACITIVE TRIMMER
TRIMMER CONNECTED TO GROUND PLANE

fig.1.

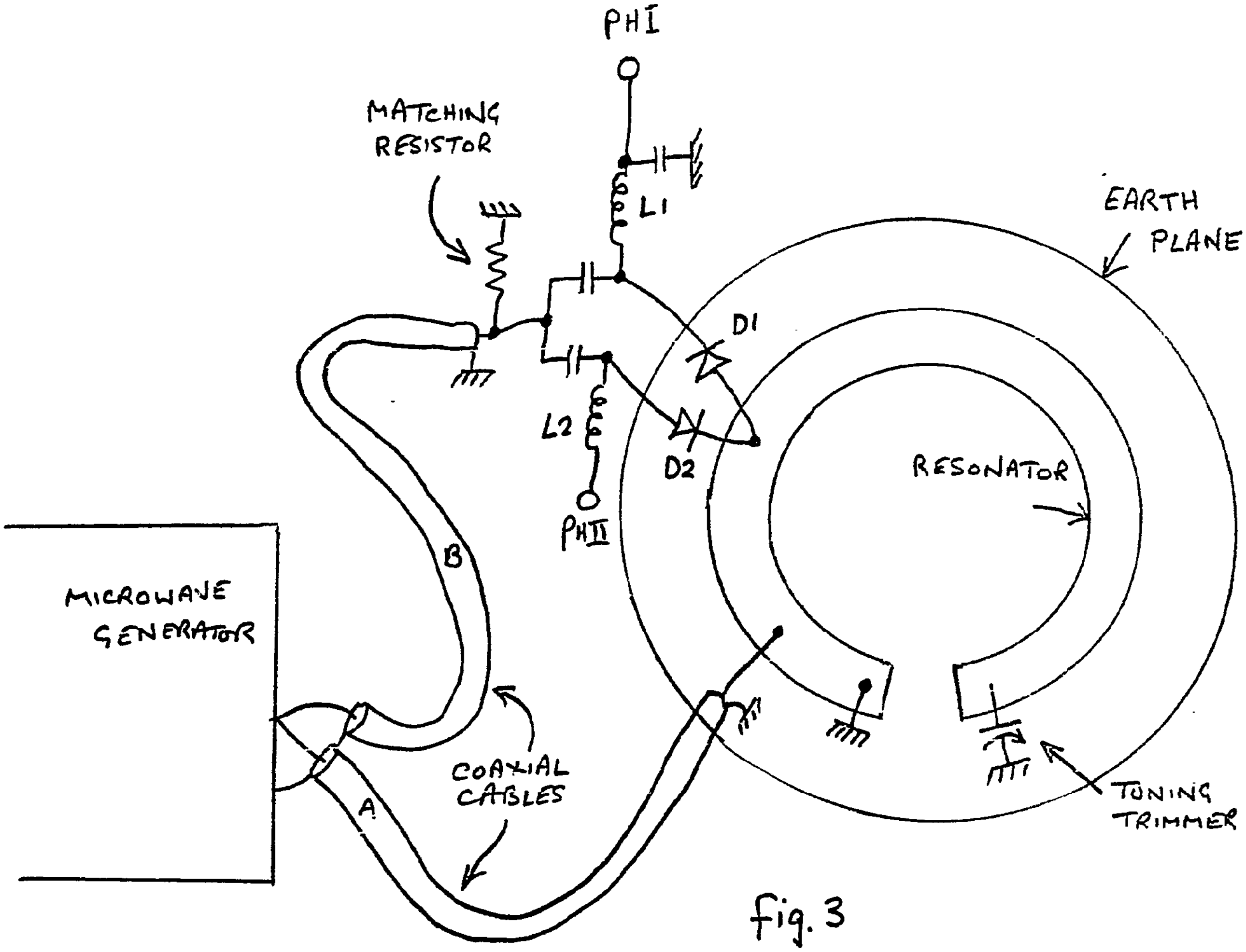

fig. 3

CONNECTIONS TO RESONATOR

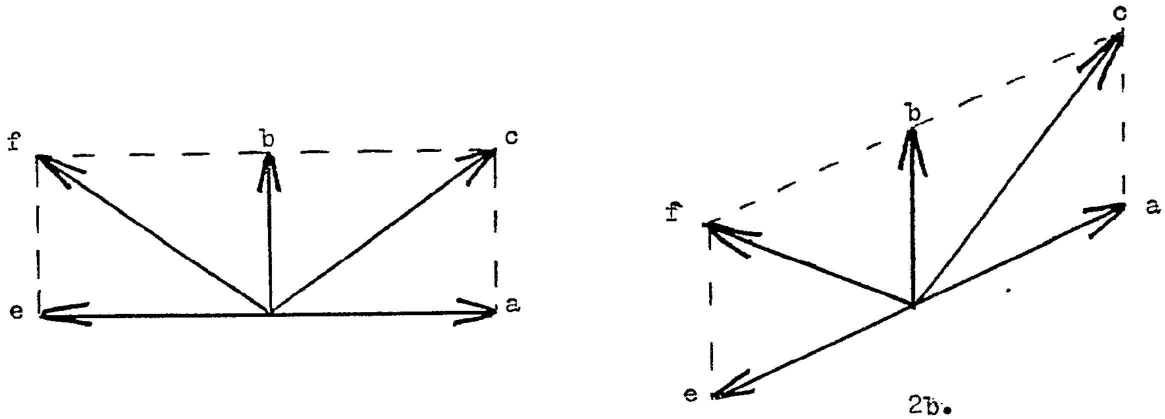
f
b
c
e
a
f
b
c
a
e
2b.

fig.2.

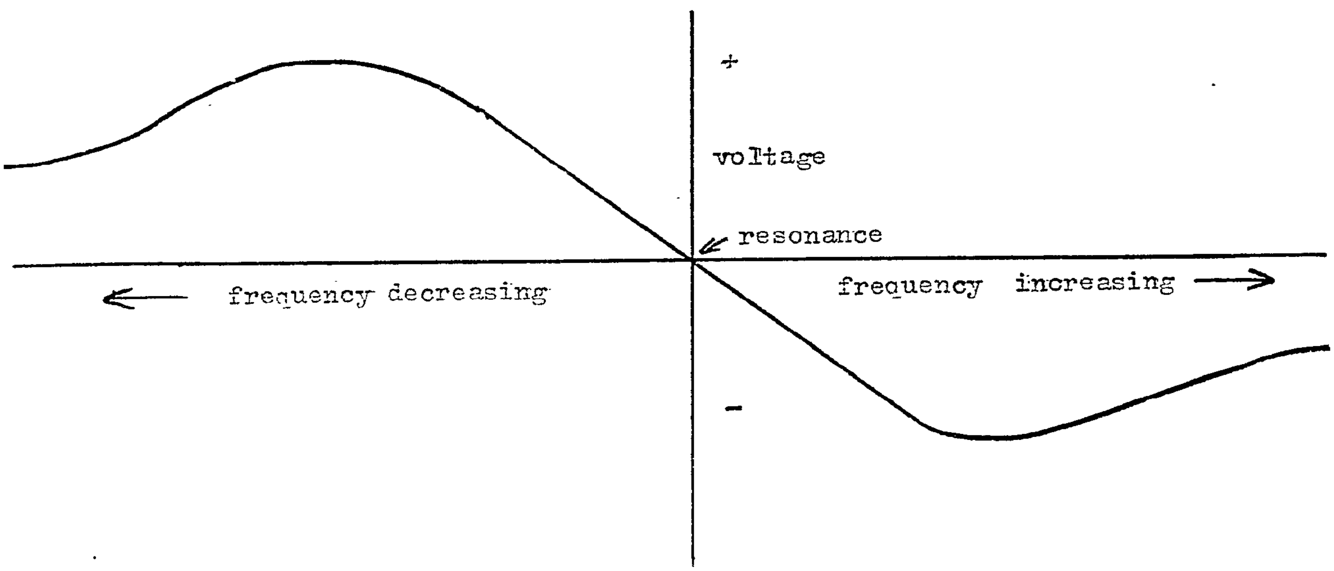
+
voltage
resonance
frequency decreasing
frequency increasing
-

fig. 4.

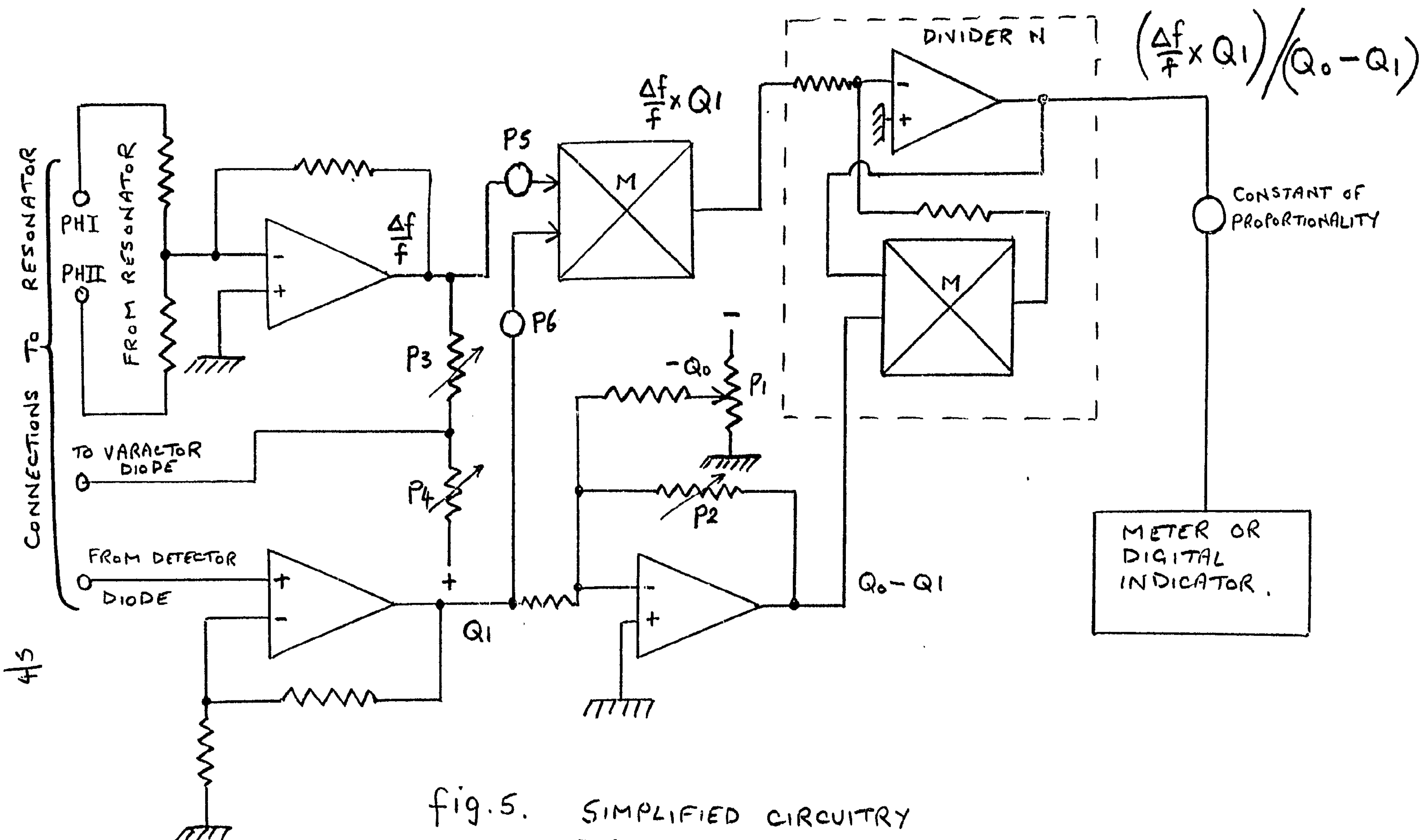

fig.5. SIMPLIFIED CIRCUITRY FOR MOISTURE MEASUREMENT

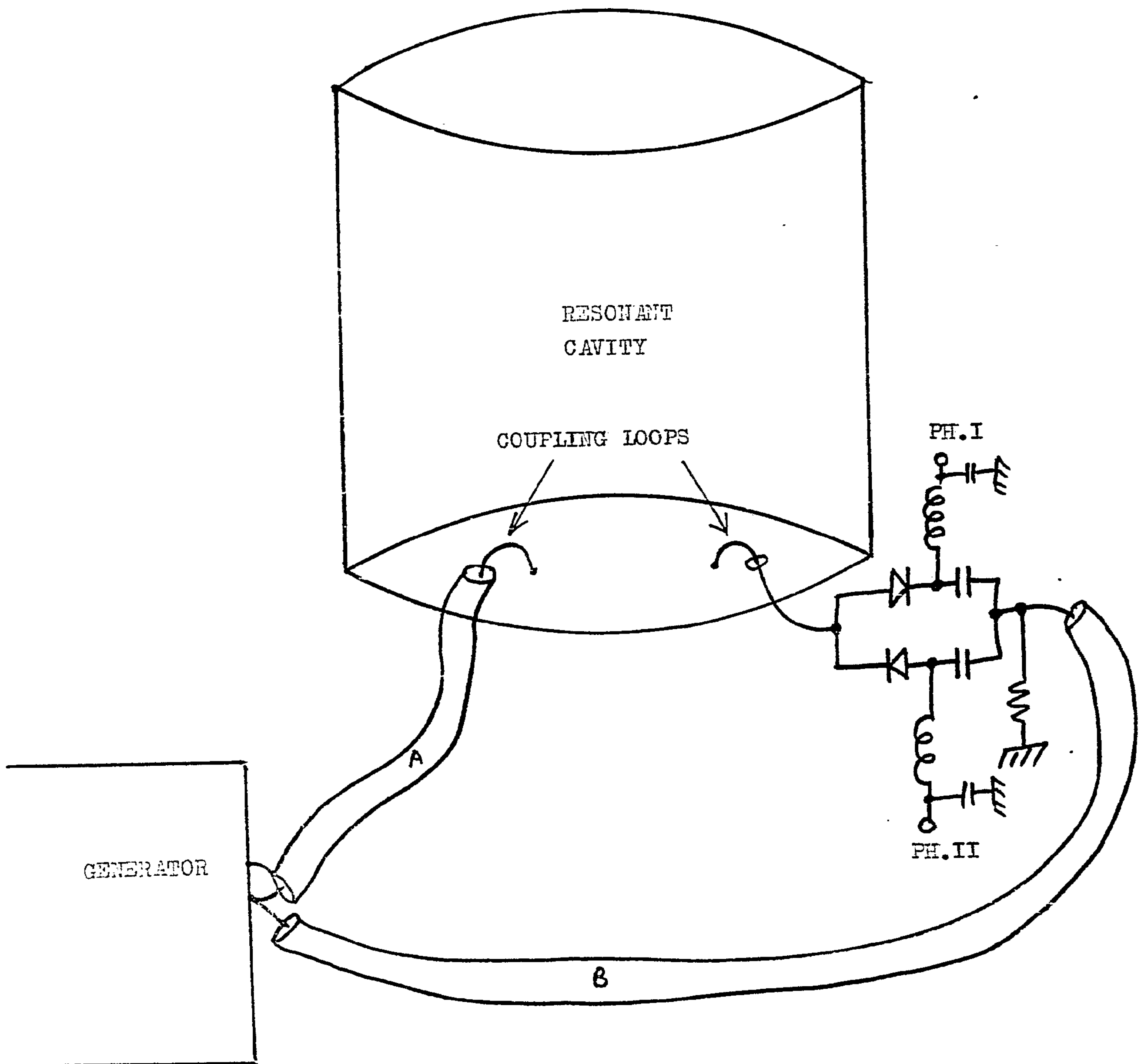

fig. 6.

2277803

I

A SIMPLIFIED METHOD FOR THE MICROWAVE DETERMINATION

OF MOISTURE WITH DENSITY CORRECTION

This application refers to the measurement of moisture in various industrial materials by means of the absorbtion of energy from high frequency radiation by a sample of moist material under test.

There are basically two methods currently in use for measuring moisture using microwave absorbtion. In one form of instrument a microwave generator feeds a radiating horn or other device for focussing the energy into a narrow beam. This is constrained to pass through the sample under test after which it is measured by concentrating the beam through a similar horn and applying it to a sensitive receiver tuned to the frequency of the microwave source. The loss of amplitude which occurs when the beam passes through the sample is due to the absorbtion of energy by the water molecules and can be measured by the receiver. This loss of amplitude is a function of the moisture content of the material tested.

The use of two sensor heads in this system, one to radiate the beam and one to receive it, is inconvenient for several reasons. Because the energy has to be transmitted in the form of a narrow beam some form of focussing device is necessary. This requires a horn or parabolic dish the dimensions of which are determined by the frequency in use. This limits the range of frequency which must be high if the size of the radiator is not to become inconveniently large. The two horns for transmitter and receiver must be accurately aligned and thereafter not moved if the calibration is not to change. There is a certain spillage of radiation which has to be screened since it can interfere with other equipment and this radiation can be reflected off of external objects giving spurious readings and generating standing waves which can cause innaccuracies.

It is for the above reasons that an alternative system using a single head comprising a high frequency resonator which produces an electromagnetic field interacting with the sample material is sometimes used. The field does not have to be focussed and the system enables lower frequencies to be used which reduce the risk of standing waves and at which the relaxation time of the water molecules is such as to enable them to respond to the electromagnetic field. The principle used is to provide a resonant system which may be in the form of a cavity or may be made from various types of stripline or microstrip circuitry. Leakage of the field is allowed to occur and this links with the test material. The moisture in the material under test absorbs energy from this field which lowers the Q factor of the resonator. This can be interpreted in terms of the percentage moisture in the sample.

It can be shown that moist materials exhibit a complex dielectric constant which has real and imaginary components. Moreover, it has also been shown that for many materials there is a direct relationship between the ratio of the two parameters of the complex dielectric constant and the density of the sample material. The failure to allow for the variation in density of the sample material has been the greatest source of error in this form of industrial moisture measurement in the past. By utilising a method of measurement whereby the two parameters of the dielectric constant are both separately measured the density may be calculated and allowed for in the measurement and considerably greater accuracy can be obtained. Moreover, much greater freedom from the need to recalibrate the instrument for different sample materials with different densities may be achieved. The present application is concerned with this type of measurement. The dielectric constant of a material containing moisture depends upon both the permittivity of the water and also the permittivity of the material containing the water

and by measuring the complex permittivity the moisture content may be easily calculated in a way which may be independent of the density over a wide range.

In a practical case this resolves itself into measuring both the attenuation coefficient and the phase constant of an electromagnetic wave radiated through the moist material. Alternatively, where a resonant system is used, the small frequency change at resonance is determined as well as the change in Q factor when energy is absorbed from such a system by moisture.

The complex dielectric constant ϵ may be expressed as follows : $\epsilon = \epsilon' + j\epsilon''$ where ϵ' is the real component and ϵ'' the imaginary component. $j = (-1)^{\frac{1}{2}}$.

A number of research reports have shown that for a range of industrial materials the moisture is related to the ratio; $\epsilon''/\epsilon'-1$ and this function is largely independent of the density.

The real component is related to the attenuation of a microwave signal or to the reduction in Q factor of a resonator and is relatively easy to measure. It is somewhat more complicated, however, to measure the phase constant, or in the case of a resonator, the small natural change in resonant frequency when the field links with the moist material and the purpose of this applicatior is to describe a very sensitive but simple system for making this measurement which enables a small inexpensive portable instrument to be produced.

A resonator may take the form of a stripline on a double sided printed circuit board or may be constructed from a solid conductor mounted above a flat conducting ground plane. A circular form is shown in fig.I. though any configuration may be used. One end of the conductor is connected to the ground plane and a length which is a multiple of one quarter of a wavelength at the microwave frequency used is suitable for the conductor. For multiples of one quarter of a wavelength the ring will have a gap as shown, the oposite end to the earthed end being open and may be conveniently tuned by means of a capacitive trimmer. For a resonator of length equal to multiples of one half wavelength both ends of the resonant section must be earthed and where the ring is one wavelength long the ring may be continuous. In this case the tuning trimmer is connected to a high impedance point on the ring. It is convenient to increase the axial sensitivity by attaching a small capacitive plate to a high impedance point on the resonator to concentrate the field along the axis.

Energy is coupled from the generator by means of a short coaxial cable matched to the output of the generator and to a point on the resonator which is equal in impedance to the impedance of the cable, near the earthed end of the resonator. The generator is of constant frequency and consists of a conventional crystal controlled oscillator and a number of frequency multiplier stages to produce the microwave frequency used. The high frequency voltage in the resonator at resonance can be detected by connecting a high frequency diode at any point on the ring to detect this voltage. Providing allowance is made for the non linearity of the diode characteristic at low voltages the D.C. voltage obtained after filtering is proportional to the Q factor of the resonator.

A method is proposed whereby an additional voltage output is produced directly from the resonator described above which is proportional to the microwave frequency to which the resonator tunes in such a way that when the frequency of the resonator is changed by the presence of moisture in the field of the resonator an output D.C. voltage is obtained after detection by high frequency detector diodes which is a linear representation of the change in resonant frequency due to moisture. Such a resonator at resonance

and fed with energy from a constant frequency generator by a correctly matched coaxial cable offers a resistive load to the cable. The current therefore in an inductive coupling is in phase with the voltage at the end of the cable and the voltage in the tuned resonator will be lagging by 90° on this voltage. In general due to the delay in the coaxial cable the phase of the voltage in the resonator will be further lagging relative to the generator output. Consider the diagram shown in fig.3. in which the resonator R is connected via coaxial cables A and B to the generator matched into both of these cables. The phase of the voltage in the resonator may be shown by the vector **a** in fig.2. If the length of the coaxial cable B is one half wavelength longer than A the phase of the voltage at the end of this cable will be as shown by vector b in fig.2. i.e 90° leading on a . The diode D1 "sees" the resultant of these two voltages and therefore produces an output rectified voltage proportional to the length of vector **c** . This appears at the end of the R.F. choke and after filtering by means of the capacitor becomes phase output PH.1. The detector diode D2 which "sees" the resultant of the voltage at the end of cable B and the opposite phase to a since this diode is reversed. This provides a voltage proportional to the length of vector f which is the resultant of b and e. This is a negative voltage of the same amplitude as that at the end of the choke L1 . Therefore the voltage after filtering at the end of choke L2 is the output PH2.

If these two voltages PH1 and PH2 are added therefore by an operational amplifier the output is zero. When a moist sample is placed within the electromagnetic field of the resonator the resonant frequency will change as well as the effective Q factor. This is due to the complex dielectric constant of the water. The frequency of the generator, however, will remain constant as this is crystal controlled so that the resonator no longer presents a resistive load to the cable and the angle between the the vector b and the voltage in the resonator is no longer 90° . The vectors change as shown in fig 2b., a and e are of course still antiphase, however, the vector a now leads relative to its initial condition as does the vector e . The diodes D1 and D2 still see the resultants of the vectors a and b, and e and b respectively. These are now no longer equal and the resultant output of an operational amplifier, or at the junction of the two input resistors, is not zero. Moreover this output voltage will be proportional to the change in frequency of the resonator over a considerable range.

The output of an operational amplifier will vary with effective resonant frequency of the resonator as shown in fig.4. The centre of the characteristic is the natural frequency of the resonator when no moisture is present to interact with the field. To ensure that the simple diode output which is representative of the Q of the resonator is accurate it is proposed that the output voltage of the operational amplifier mentioned above added to a suitable bias voltage be applied to a varactor diode connected to the resonator in such a way that the resonator is retuned back to its original natural frequency. The varactor capacity change is such that an increase in capacity due to the presence of water is matched by an equivalent decrease in the capacitance of the varactor diode. The voltage necessary on the varactor to do this is taken as the parameter related to the actual change in frequency which would have occurred without the varactor. Thus the voltage on the varactor diode is a voltage proportional to the frequency change which would occur in the resonator due to the complex permittivity of the water present in the sample material. Under these conditions the change in amplitude of the R.F. voltage in the resonator is a measure of the change in Q factor. This is detected by the detector diode D3.

The system therefore, of resonator, generator, and detector diodes produces

two D.C voltages. One of these is proportional to the change in frequency which would occur, and the other is proportional to the change in Q factor which would occur in a microwave resonator when the electromagnetic field produced by this resonator is linked with a sample material containing water.

These two parameters are also related to the parameters ϵ' and ϵ'' of the complex dielectric constant of the material containing the water. It has been shown using perterbation theory in a number of scientific papers that for small perterbations in a resonant system the function $\epsilon'-1/\epsilon''$ is equal to the relationship

$$\frac{\frac{2(f1-fo)}{f1}}{\frac{1}{Q1}-\frac{1}{Qo}}$$

and this is a good indication of the moisture content while being effectively independent of the density of the material. Where fo is the frequency of the resonator without moisture present, f1 is its frequency when moisture is in its field. Qo is the Q factor of the resonator when no moisture is present, Q1 is the Q factor when the moisture is in the field.

$$\frac{\epsilon'-1}{\epsilon''} = 2\,\frac{\Delta f}{f_0}\Big/\frac{1}{Q_1}-\frac{1}{Q_0} \qquad \left[\frac{\Delta f}{f_0} \simeq \frac{f_1-f_0}{f_1}\right]$$

which may be written :

$$\frac{\epsilon'-1}{\epsilon''} = 2\,\frac{\frac{\Delta f}{f_0}\,Q_0\,Q_1}{Q_0-Q_1}$$

and since Qo and fo are constant

$$\frac{\epsilon'-1}{\epsilon''} \propto \frac{\Delta f}{f_0}\,Q_1\Big/Q_0-Q_1$$

These parameters are all available from the system described above, the calculation of $\epsilon'-1/\epsilon''$ is relatively simple using either analogue or digital methods.

$\Delta f/f_0$ is proportional to the output of the operational amplifier referred to above and Q1 is proportional to the voltage obtained from the diode detector D3. Qo is constant and is the voltage output of D3 before any perterbation due to moisture takes place.

An example of a simple analogue system to calculate the value of $\epsilon'-1/\epsilon''$ in the above function is outlined below.* This enables a small portable moisture measuring instrument to be produced using these principles. An alternative digital system is, of course, possible and by converting the voltages obtained from the measuring resonator system after amplification into digital form these can be fed directly into a micro-computer and the calculation of moisture performed automatically by programme.

* fig. 5.

Consider the diagram fig.5. The output of amplifier 3 is initially set to zero by means of the potentiometer P1 when no moist material is near to the resonator. The voltage on P1 is therefore representative of Qo. When moist material is near to the resonator and its Q factor decreases to Q1 the output of amplifier 3 will be proportional to Qo-Q1 and this can be scaled by means of the gain potentiometer P2.

The phase inputs PH1 and PH2 from the resonator diodes D1 and D2 are connected through the resistors R1 and R2 to the summing junction of the operational amplifier 1. The output of this amplifier which is zero when no moisture is presented to the resonator is proportional to the resonator frequency change when moisture is present, i.e is proportional to the quantity $\Delta f/f_0$. The output of amplifier 1 along with a suitable D.C. bias adjusted by potentiometers P3 and P4 is applied back to the varactor diode in the resonator to retune the resonator when it is perturbed by moisture. Both the output of amplifier 2 representing the quantity Q1 and the output of amplifier 1 representing $\Delta f/f_0$ are applied to an analogue multiplier M. This produces the product of these two quantities which are then divided by the output of amplifier 3 which is Qo-Q1 using an analogue divider N to produce the expression calculated above. No scaling is shown on the simplified diagram since this depends upon the characteristics of individual components.

The simple arrangement shown above when carefully calibrated is capable of indicating on an analogue or digital meter the moisture level in a number of industrial materials to a high degree of accuracy which is almost independent of the density of the material.

In another embodyment of the method the resonator is in the form of a resonant cavity which may be cylindrical or rectangular in form. The phase of the voltages in the cavity being compared via coupling loops to the phase of the voltage at the end of a coaxial line as in the case of the previously described resonators. A typical arrangement is shown in fig.6. where a cylindrical cavity is shown with two coupling loops. There are a number of modes which may be used for the moisture measurement and the position of the loops will vary depending upon which mode is used. In some cases it is advantageous to use a voltage probe instead of an inductive loop where the electric field is to be stimulated instead of the magnetic field. In some configurations it is also advantageous to include means to suppress certain modes which can interfere with the mode chosen to be used. Normal cavity techniques will apply in these cases.

CLAIMS

1. A method of determining moisture in industrial materials which is independent of the density of the sample material, by measuring the amplitude of the voltage and the change in frequency in a microwave resonator coupled to the wet material. The frequency change in the resonator being determined by the change of phase of the voltage in the resonator compared to the phase due to the delay in a section of coaxial line.

2. A method by which two microwave diodes are arranged to experience the difference between two voltages which vary in phase so that they detect the phase differences and produce a rectified output which is proportional to the frequency change in a microwave resonator coupled to a moist sample.

3. A method as in 1. in which a resonator is used to measure moisture. The resonator being a section of stripline or microstrip printed circuit board, a conducting bar, or a cavity.

4. A method as in 1. in which a varactor or variable capacitance diode is used to retune the resonator to its unperturbed frequency when the resonator is perturbed by the presence of a moist sample. Thus making the voltage in the resonator proportional to the Q factor of the resonator.

5. A method as in 1. where by using the two parameters obtained from the resonator the moisture may be indicated in a way independent of the density of the sample material.

6. A method as in 1. in which the resonator is in the form of a resonant cavity into which the moist sample is placed. The cavity being wired in such a way that the two parameters required to calculate the moisture may be obtained by the two diodes as in 2.

7. A method as in 1. in which the density may be measured instead of or in addition to the moisture in a sample material.

Amendments to the claims have been filed as follows

CLAIMS

1. A method of measuring the moisture in industrial materials using the well established principle of deriving the parameters of the complex dielectric constant from the Q factor and frequency of a microwave resonator coupled to the moist material but which requires only a single frequency to energise the resonator, does not require any other measuring apparatus to be used, does not require the energising frequency to be variable or swept through the frequency of the resonator, and does not require the frequency to be modulated in any way or the Q factor to be measured with any other instrument.

2. A method outlined in 1. in which the change in frequency of a resonator is indicated directly by a D.C. voltage obtained from two semiconductor rectifying devices i.e microwave diodes,arranged to detect the difference between two microwave voltages which vary in phase so that the phase difference between them is proportional to the frequency change in the resonator when perturbed by the presence of moisture. One of these microwave voltages is derived from the voltage in the resonator, the other from a deliberately induced delay in transmission through a coaxial cable.

3. A method as in 1. and 2. in which the D.C. voltage proportional to frequency obtained as described in 2. is fed back to a varactor or variable capacitance diode connected to the resonator such that the frequency is returned to its unperturbed value when the resonator is detuned by the presence of water. The frequency to which the generator is tuned is therefore unaltered when moisture is detected. The D.C. voltage fed back to the varactor is then proportional to the frequency change which would have occurred and the amplitude of the voltage remaining in the resonator is then proportional to the Q factor of the resonator.

4. A method as in 1.,2., and 3. in which the frequency of a resonator which is unchanged when it is perturbed by the presence of moisture provides two D.C. voltages. One proportional to the frequency change which would have occurred, the other, by rectifying the voltage in the resonator is proportional to the Q factor of the resonator.

5. A method as in 1., 2., 3., and 4., in which the resonator is in the form of a tuned ring one quarter of a wavelength long in which the electromagnetic field produced is coupled to the moist material to be measured.

6. A method as in 1., 2., 3., and 4., in which the resonator is in the form of a section of strip line printed circuit board or microstrip board or in the form of a conducting bar.

7. A method as in 1., 2., 3., and 4., in which the resonator is in the form of a resonant cavity into which the moist sample is placed. The voltages proportional to Q factor and resonant frequency being obtained from coupling loops within the cavity.

8. A method of using the voltages derived in 1., 2., 3., and 4., to calculate the moisture directly and suitable for use in a portable instrument.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report) -9-	Application number GB 9309221.1
Relevant Technical Fields (i) UK Cl (Ed.M) G1N CCR (ii) Int Cl (Ed.5) G01N	Search Examiner T OLDERSHAW Date of completion of Search 28 APRIL 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE DATABASES: WPI	Documents considered relevant following a search in respect of Claims :- 1-7

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A,E	GB 2271637 A	(GEC-MARCONI)	
A	GB 2260408 A	(UNAFORM)	
A	GB 2202947 A	(UKAEA) see eg page 5 lines 4-20	
A	EP 0292571	(DIPOLE) see eg page 5 line 14 - page 6 line 24	

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).